Fire Dynamics and Safety

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1. Introduction

Catastrophic fires still occur, and many people still don't realize just how quickly a seemingly simple fire can grow rapidly into an inescapable furious inferno. Information, analysis and calculations of fire dynamic phenomena can assist in understanding and applying scientific information to real-world fire situations. Recent extensive study, research, experimentation and field observations and measurements have led to the need for critical evaluation of fire phenomena and its simulation, see Lilley (2004) and NFPA (2004). Fire dynamicists can develop an appreciation for technical/scientific understanding of the phenomena and its applicability to real-world practical down-to-earth situations.

2. Key Features

Fire behavior is extremely important in fire protection engineering and building design engineering. The ultimate goal of modeling studies is to improve scientific and technical understanding of fire behavior leading to flashover in structural fires. The development of the fire analytical modeling has accelerated over the last 30 years. As a result, fire modeling can often be used to appraise the effectiveness of the protective measures proposed when one designs a building. Zone-type and field-type computational fluid dynamic CFD modeling approaches to multi-room structural fire modeling are available.

Fires produce acutely lethal products of combustion, including smoke, carbon monoxide, hydrogen cyanide, acrolein, hydrogen chloride, nitrogen oxide(s), etc. in addition to heat and insufficient oxygen. These gases are produced in large quantities and driven to remote areas, causing life-threatening situations -- inhalation of fire gases (toxic products of combustion) being the major cause of death in fires. For these reasons, any combination of finishes, combustible building materials, or contents and furnishings that could result in flashover (full room involvement) in a few minutes represents a severe fire hazard in many types of occupancies. Protection by automatic sprinklers and fire-rated construction separations is often needed, and/or mandated by the relevant code. Computer fire models include the mathematical characterization. One can then assess whether an especially hazardous situation exists -- whether a given fire scenario has the potential to develop flashover or full room involvement.

Slow, medium, fast and ultra-fast fire growths may be specified by the t^2-fire growth model, where, after an initial incubation period,

$$\dot{Q} = \alpha_f t^2$$

where α_f is a fire-growth coefficient (kW/s^2). Suggested values for the coefficient a_f are as follows:

Slow:	0.002778 kW/s^2 with growth time to 1 MW of 600 seconds
Medium:	0.011111 kW/s^2 with growth time to 1 MW of 300 seconds
Fast:	0.044444 kW/s^2 with growth time to 1 MW of 150 seconds
Ultra Fast:	0.177778 kW/s^2 with growth time to 1 MW of 75 seconds

The above has provided information about the burning rate (heat release rate vs. time) of a single specified item in the burn room. What happens next? Either the item burns out without further damage to the surroundings, or one or more nearby items ignite and add fuel to the fire. As the radiant energy flux rate increases from the first item to the second, often a simple criterion for ignition of the latter is used. A good approximation is that the radiant heat flux (arriving on the surface of the second item) necessary to ignite the second item is:

10 kW/m^2:	Easily ignitable items, such as thin curtains or loose newsprint
20 kW/m^2:	Normal items, such as upholstered furniture
40 kW/m^2:	Difficult to ignite items, such as wood of 0.5 inch or greater thickness

For many enclosure fires, it is of interest to estimate the radiation transmitted from a burning fuel array to a target fuel positioned some distance from the fire to determine if secondary ignitions are likely. Considerations of inverse square distance lead to the equation:

$$\dot{q}''_o \approx \frac{x_r \dot{Q}}{4\pi r^2}$$

where $\dot{q}''_o$ is the incident radiation flux on the target (kW/m^2), r is the distance (radius) from the fire to the target fuel (m), x_r is the radiative fraction, and $\dot{Q}$ is the total heat release rate of the fire (kJ/s) or (kW).

Useful related calculations are exhibited in Table 1. Here the heat flux in kW/m^2 landing on a target is given as a function of total heat release rate $\dot{Q}$ in MW and distance away in meters, with an estimated radiative fraction x_r of 0.4 being used.

Table 1. Heat Flux $\dot{q}''$ in kW/m^2 on Target.

Source Total Heat Release $\dot{Q}$ MW	Distance of Target from Source			
	1 m	2 m	5 m	10 m
1	31.8	7.96	1.27	0.32
5	159.0	39.80	6.37	1.59
10	318.0	79.60	12.70	3.18

3. Conclusions

Structural fire development can be understood more readily when technical knowledge puts the phenomena on a firm scientific footing. The theory assists in understanding and applying scientific information to real-world fire investigation situations. Recent extensive study, research, experimentation and field observations and measurements have led to the need for critical evaluation of phenomena and its simulation. Fire dynamicists can develop an appreciation for technical/scientific understanding of the phenomena and its applicability to real-world practical down-to-earth situations.

4. References and Bibliography

1. Lilley, D.G, 2004, "Fire Dynamics," Short Course, Lilley & Associates, Stillwater, OK, USA.
2. NFPA 921, 2004, "Guide for Fire and Explosion Investigations," NFPA, Quincy, MA, USA.

Author Biography

David G. Lilley is a Professor in the School of Mechanical and Aerospace Engineering, Oklahoma State University, USA, with expertise in combustion aerodynamics. His active consulting practice Lilley & Associates is primarily concerned with litigation emphasizing fires, combustion, fuels, aerodynamics, fluid dynamics, heat transfer, fuel sprays, and computer simulation. He was born in England and obtained his education at Sheffield University, from which he received the Bachelor and Master degrees in Mathematics in 1966 and 1967, and the Ph.D. degree in Engineering in 1970. The "higher doctorate" D.Sc. degree was awarded in 1991 by Sheffield University for many years of successful research, publication of high quality original research work, international recognition, and standing as an authority in the field Combustion Aerodynamics. The "Energy Systems Award" was given in 1992 by AIAA for distinguished contribution as a teacher, researcher and consultant in the areas of swirl flows in combustors and furnaces, mathematical modeling, fuels and fires. In 1993 he was elected to the grade of Fellow of the AIAA - an honor bestowed upon people of distinction who have made notable and valuable contributions to the arts, sciences, or technology of aeronautics or astronautics. In 2000 he was elected to the grade of Fellow of the ASME and awarded the "George Westinghouse Gold Medal" for notable contributions to the Power Field of Mechanical Engineering, specifically for distinguished contributions as a teacher, researcher and consultant in power engineering, including the publication of quality scholarly papers and studies on safety, energy efficiency and environmentally compliant power systems.